Real-Time Forecasting System of Winds, Waves and Surge in Tropical Cyclones

Hans C. Graber, Mark A. Donelan and Michael G. Brown
RSMAS - Applied Marine Physics, University of Miami
4600 Rickenbacker Causeway, Miami, FL 33149-1098, USA
phone: (305) 411-4935, fax: (305) 411-4701, email: hgraber@rsmas.miami.edu

Donald N. Slinn
Civil and Coastal Engineering Department, University of Florida
Gainesville, FL 32611-6590
phone: (352) 392-1436 x1431, email: slinn@coastal.ufl.edu

Scott C. Hagen
Civil & Environmental Engineering, University of Central Florida
P.O. Box 162450, Orlando, FL 32816-2450
phone: (407) 823-3903, fax: (407) 823-3315, email: shagen@mail.ucf.edu

Donald R. Thompson
The Johns Hopkins University, Applied Physics Laboratory
11100 Johns Hopkins Road, Laurel, MD 20723-6099
phone: (240) 228-4559, fax: (240) 228-5548, email: donald.thompson@jhuapl.edu

Robert E. Jensen
USAEWES, Coastal and Hydraulics Laboratory, Research Division,
3909 Halls Ferry Road, Vicksburg, MS 39180-6199 USA
phone: (601) 634-2101   fax: (601) 634-4314 email: jensen@madmax.wes.army.mil

Peter G. Black and Mark D. Powell
NOAA/AOML, Hurricane Research Division
4301 Rickenbacker Causeway, Miami, FL 33149 USA
phone: (305) 361-4320   fax: (305) 361-4402   email: black@aoml.noaa.gov

John L. Guiney,
DOC/NOAA/NWS-Eastern Region, Eastern Region Headquarters
630 Johnson Avenue, Bohemia, NY 11716 USA
phoe: (631) 221-0121, fax: (631) 221-0167, E-mail: John.Guiney@noaa.gov

Vincent J. Cardone, and Andrew T. Cox
Oceanweather, Inc.
5 River Road, Suite 1, Cos Cob, CT 06807 USA
phone: (203) 661-3091   fax: (203) 661-6089   email: vcardone@oceanweather.com

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LONG-TERM GOALS

The long-term goal of this partnership is to establish an operational forecasting system of the wind field and resulting waves and surge impacting the coastline during the approach and landfall of tropical cyclones. The results of this forecasting system would provide real-time information to the National Hurricane Center during the tropical cyclone season in the Atlantic for establishing improved advisories for the general public and federal agencies including military and civil emergency response teams.

OBJECTIVES

1) To define output products necessary to enhance the guidance skills of the Tropical Cyclone Forecast/Advisory product.
2) To test the model infra-structure that would lead toward better forecast information for landfall hurricane wind, wave, and surge conditions. Several historical storms will be used to assess model infra-structure.
3) To develop the interface that couples high-resolution cyclone wind fields to the selected wind model.
4) To develop a system that couples storm surge and spectral wave models driven by winds specified in 6).
5) Test entire system via a proof-of-concepts approach with data from several historical hurricanes.
6) Test system in semi-operational mode during several hurricane seasons and begin transition to fully operational mode.

APPROACH
So far the 2005 hurricane season was one of the best "real tests" of the forecasting model system for winds, waves and surge. With unprecedented active storm season of 26 named storms, the 2005 season provided a major challenge to the forecast system with having multiple storms present in all basins as well as little downtime between storms. Several major hurricanes such as Katrina, Rita and Wilma tested the system with extreme high winds, waves and surge. As always the system spins up automatically with the first discussion message posted by the National Hurricane Center, even before June 1 and is running uninterrupted in real time when a storm is present and provides graphical output accessible through a website in an operational mode. This year Tropical Storm Andrea formed on May 9 and the NOPP system automatically started and began its forecasting cycles. Note that NOAA WaveWatch-III system was still shut down for another 3 weeks and did not provide any forecasts for TS Andrea. During this last year the focus of the project was to make final improvements to the wind, wave and surge models and in particular the graphical output, strengthening of the interfaces and the links to access of external data sources. H*Wind snapshots from NOAA/AOML were produced on a three-hourly cycle instead at synoptic times for more timely initialization of the wind fields. We were also operating fully within the six-hourly advisory cycle of the National Hurricane Center (NHC) and made results available to NHC for evaluation purposes via our web interface. This year we include runs for the ensemble of alternate tracks which will be used to provide risk factors of exposure to winds, waves and surge.

WORK COMPLETED

1. Completed the moderately active 2007 hurricane season in fully automated, "operational" mode. Two major hurricanes, Dean and Felix, developed into category 5 storms.
2. The WINDGEN system continued to perform excellent during this extremely active hurricane season with many super-type hurricanes. The system is ready for operational use and we have tested a higher resolution grid covering the entire area at 10 km and 15 minute intervals.
3. Wave and surge models have been coupled to include the effect of momentum input (radiation stress) from breaking waves on sea-level rise in coastal regions.
4. Numerous improvements have been made to the WAM model, in particular, the wave growth algorithm has been modified to include the drag coefficenit relationship of Donelan *et al*. (2005).
5. Tidal dynamics are fully integrated into the surge predictions.
6. Surge model is fully integrated into forecast system to run in real-time.
7. We have added all alternate track forecasts deemed of importance to the NHC (currently about dozen) to the computational cycle.
8. We have continued to improve our graphical display formats and posting to website (http://hurricanewaves.org). In particular, results are now displayed on GoogleEarth.

RESULTS

Wind Field Generation Program:

The WINDGEN program is in its third iteration and has been successfully applied during the 2005 hurricane season and is currently running for 2006. All required real time acquisitions of track, H*WIND snapshots, background fields from NCEP and alternate track information required by the WIND GENeration program (WINDGEN) are automatically accessed and retrieved. In addition, wind/wave validation data from NDBC (National Data Buoy Center) and water level/tide data from NOS (National Ocean Service) are being ingested in real time. All scripts have been running throughout the hurricane season and are robust and stable and keep performing well. The WINDGEN program can input either H*WIND analysis or perform its own wind field generation using the TC96 tropical boundary model. The program also provides wind/pressure output for numerous alternate track models for use by the modelers. Numerous upgrades were made to the WINDGEN software during the 2004/2005 period. Native ADCIRC output is now built into the model. This integration not only saves time during the forecast run, but also makes use of WINDGEN's space interpolation routines to better describe the stress and pressure inputs on the ADCIRC grid. The surge modelers can easily apply updates to the ADCIRC output as new grids/domains are tested and brought online into the operational system. As a result of post-analysis work done on Hurricane Ivan 2004, the blending of the H*WIND/TC96 into the GFS background field has been adjusted. This results in wind fields that better blend into the synoptic flow. Additional work on the WINDGEN code involved the handling of bad/erroneous winds data and better failover if bad data is encountered. The latest version of WINDGEN is run operationally on GERONIMO at 0.2 degree and SATANTA at 0.1 degree currently for post-storm analyses. Figure 1 shows a MODIS and the NOPP track forecast for Hurricane Dean, which turned into a monster storm with 165 mph winds and a central low pressure of 906 mb. Dean eventually slammed into Mexico's Yucatan Peninsula and caused flooding and extensive damage.
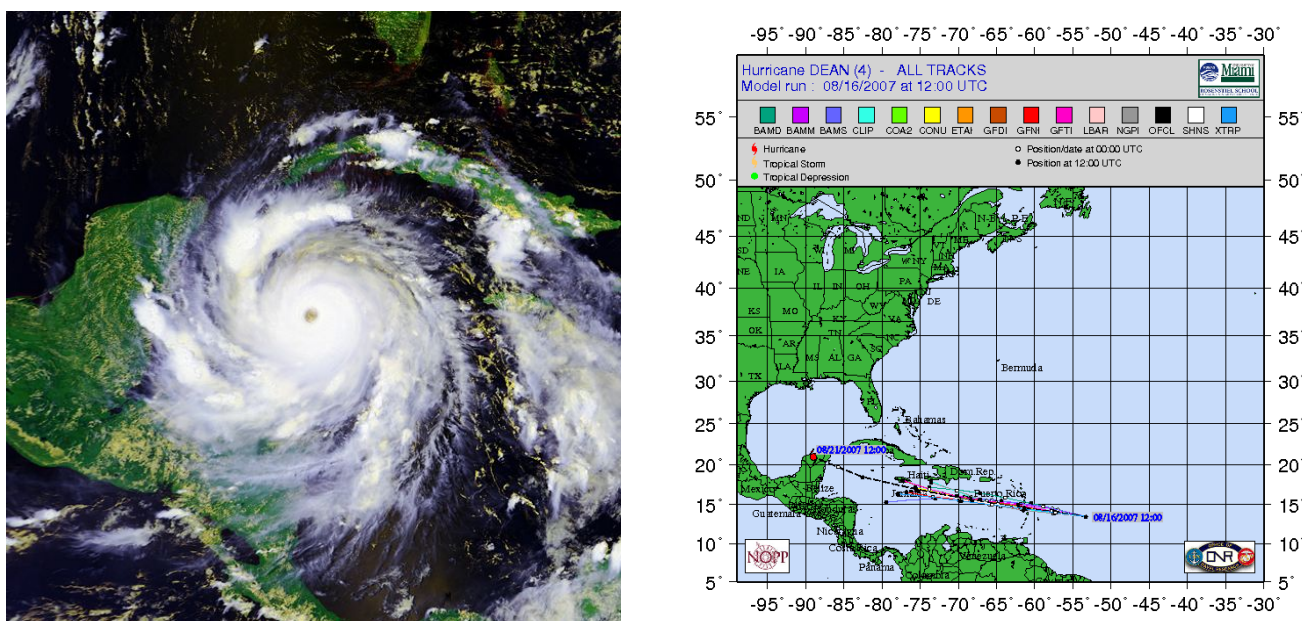
Figure 1: Left: Hurricane Dean on August 20 at approximately 1841 UTC approaching the Yucatan Peninsula. This image was produced from data from NOAA-18, provided by NOAA. Right: The NOPP 5-day track forecast showing the official forecast track (black) as well as fourteen alternate tracks .

Wave Modeling:

A fully tested and automated, operational wave forecasting system based on WAM Cycle 4.5-V2 for Hurricanes at Landfall was put in place for the 2004 Hurricane season. The 2005 Hurricane season demonstrated how robust and stable WAM performed and the quality of the wave forecasts. This was made possible by significant improvements internal to the model which led to revisions to source term specification that constrained wave growth consistent with recent behavior of the drag coefficient as the surface condition goes from aerodynamically smooth (characterized by a drop in the drag coefficient with increasing wind) to aerodynamically rough (drag coefficient increasing with wind speed), multi-grid nesting, ice coverage implementation and more importantly depth limited breaking. In the 2005/2006 season we also implemented the drag coefficient relation from Donelan et al. (2005) which shows that around 30 m/s the drag coefficient begins to level off. In addition the model has been optimized for scalable computational platforms reducing the operational constraints by a factor of 20. These improvements, and now five years of critical evaluation for the 2003 through the 2007 hurricane season by the NOPP project that included many historical tropical storm simulations produced a wave model with unprecedented performance characteristics. The latter implementation and execution provided insights into improvements in the source terms reducing significant errors in the core of tropical systems by 30-percent. Figure 2 shows the zoomed in wind and corresponding wave fields of Hurricane Dean as it passed south of Puerto Rico. These products are typically generated and available on the NOPP project website.

Surge Modeling:

We have now fully integrated the ADCIRC (Advanced Circulation Model for Coasts, Shelves and Estuaries) with the WAM Cycle-4.5 model to improve predictive skill for storm surge during tropical

cyclones. In addition to the standard ADCIRC implementation, we are also running a parallel version (PADCIRC) to achieve more efficient processing for the alternate track ensemble. Both ARCIRC
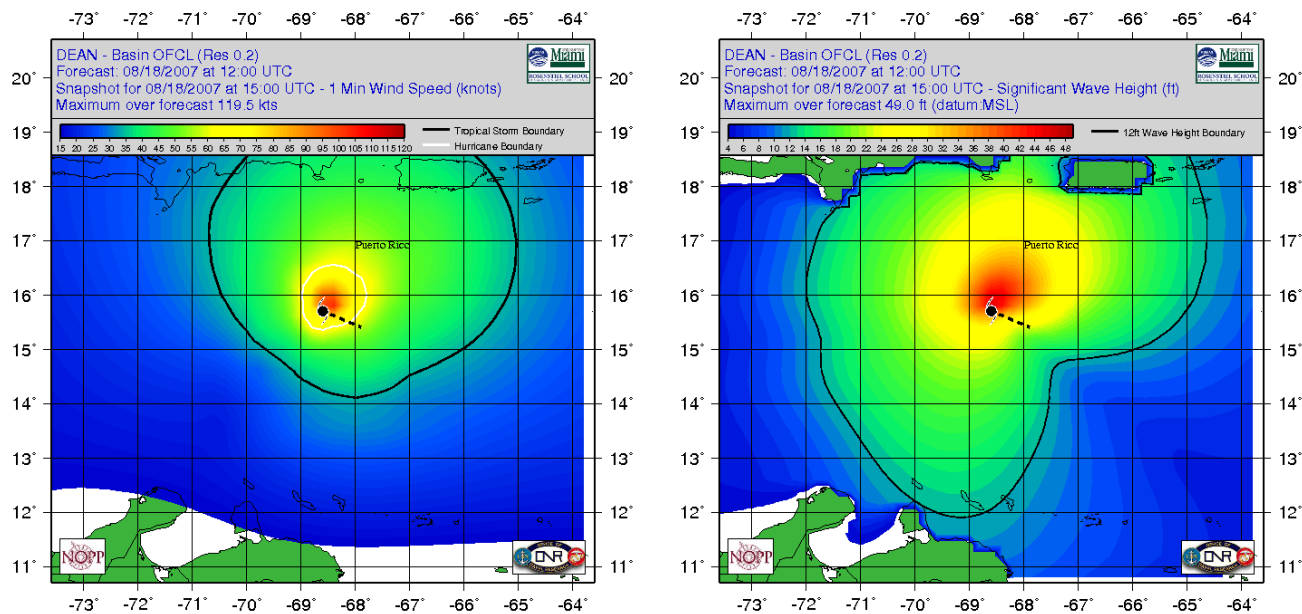

Figure 2: Left: Zoomed in wind field predictions of Hurricane Dean as it passed south of Puerto Rico on August 18, 2007 at 12:00 UTC. Maximum wind speeds reached 120 kts in the core of the storm center. Note the asymmetric distribution of winds with respect to the center and forward direction. Right: The corresponding zoomed in wave height predictions of Hurricane Dean for the same time showing maximum wave height conditions exceeding 40 ft in the northeast quadrant.

versions have been optimized and include the effects of wave through the radiation stress provided by the WAM model. Additional improvements were made by establishing an operational mesh with a minimal number of computational points (47,860, hereto referred as the 48K mesh) that produces highly accurate astronomical tide simulation results. Spatial resolution of the mesh ranges from a node spacing of approximately 160 km in the Atlantic Ocean to roughly 6 km element sizes along the coastal boundaries. This mesh can be employed in astronomic and meteorological tidal simulations with a time step of 30 seconds, permitting a five day forecast to be completed on the NOPP IBM computing system in less than 10 minutes.

IMPACT/APPLICATIONS
An improved forecast of the coastal environment under hurricane conditions has potential benefit for society in several areas. A primary benefit is the early warning and evacuation of population and mobile assets from threatened coastal areas. The storm surge modeling can also be extended to include tsunami prediction and warning capabilities.

National Security
Improved forecasting of several days in advance will help emergency planners and FEMA as well as DHS to prepare adequately for approaching tropical cyclones.
Economic Development
This forecast system could also be used to determine which coastal regions are extremely vulnerable to the impact of tropical cyclones especially caused by flooding and wave damage. New risk and

exposure maps for flooding can readily be generated with the added benefit of risk factors, i.e. not all storm may lead to flooding.
Quality of Life
Understanding better the risk to potential damage will allow the public and communities to make decisions on where to live and how to manage coastal and ecological resources.
Science Education and Communication
Assessment of operational models will identify shortcomings in the science and physics of models used for weather prediction as well as the need for the right data at critical locations and times.

TRANSITIONS
National Security
The NOPP system is now implemented for the New Orleans District of the US Army Corps to provide warning messages for wind and surge in the event when flooding conditions may arise at the three gates along Lake Pontchartrain which need to be closed beforehand.

RELATED PROJECTS
This NOPP project began to partner with SCOOP whose primary goal is to provide high-resolution storm surge predictions during severe weather phenomena such as tropical and extra-tropical storms in coastal regions along the US East coast and Gulf of Mexico. To achieve this goal SCOOP will utilize the NOPP's coupled model forecast system. Two studies started that target specific coastal and inland regions. First, a study with the NWS Southeast River Forecast Center to produce real-time tides and storm tide hydrographs for the Waccamaw River region in South Carolina. In addition, NOAA, through the NWS Office for Hydrologic Development has funded a three-year. A collaborative effort between UCF and UF led to a pilot study for the Florida Department of Transportation (FDOT), which will examine the effects that inlet shapes, as well as coupled short and long wave models have on nearshore storm tide hydrographs that are then employed in bridge scour studies.

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